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# USE OF GEOSYNTHETIC CLAY LINER AS A WATERPROOFING BARRIER IN SANITARY LANDFILLS

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**Abstract:** The soil waste disposal is one of the main sources of soil and water contamination. In this sense, sanitary landfills have great importance for environmental protection, and in these systems, the geosynthetics materials, such as the Geosynthetic Clay Liner (GCL), are widely employed. However, for landfills with leachate recirculation, the GCL application is vetoed by many government agencies. In view of this, this study sought to provide recent advances analysis in GCL application in landfill. For this reason, the main configurations of landfills and characteristics of its leachate were presented, as well as of the GCL by means of case studies applied to the context. The results indicated that hydraulic conductivity is the most important parameter to be evaluated in GCL performance, which can be influenced directly by leachate composition (conventional and recirculated) as to cations and anions presence. Thus, it's concluded that the evaluation of these characteristics is essential to ensure the proper performance of GCL in landfills.

**Keywords:** Waste disposal; Engineering works; Leachate recirculation; Proofing; Geosynthetics.



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## INTRODUCTION

Several factors have contributed to increase of soil waste generation in recent decades. Population growths, combined with the increase in agricultural and industrial production, are factors that deserve to be highlighted. A large portion of solid waste generated has no possibility of being reused, requiring adequate disposal, and then disposed in landfills, which is the last but inevitable step in management of solid waste (Dajic *et al*., 2016).

Solid waste landfills are engineering projects in continuous development. They are installations which, by nature, produce a variety of impacts on environment, such as land use or the generation of liquid and gaseous contaminants (Slack *et al*., 2005). The failure of a landfill can pose a great danger to people and the environment. One of the components widely used in landfills is the Geosynthetic Clay Liner (GCL), which is employed in coating systems that are placed under the landfill to isolate waste from surrounding environment (Feng *et al*., 2018).

The GCL is widely used in hydraulic barrier function. Its structure consists of Bentonite clay presence linked to a layer or more layers of geosynthetic material. In the 1980 began its industrialization, through the confinement of sodium bentonite between two geotextiles. A wide variety of similar products has been developed since then, aiming to improve performance and meet new applications (Fox & Stark, 2015).

The Geocomposite Bentonite can be classified through physical properties, such as bentonite (sodium or cyanamide), thickness, coating and moisture content, as well as by its structural formatting: non-reinforced, where the bentonite is attached to the geosynthetic through adhesive; and reinforced, where the layers are interconnected with each other by sewing. The diversity of this material softened its use as environmental control, using landfills, reservoirs and storage tanks of contaminants (Koerner, 2005).

The GCLs present permeability near $10^{-11}$ m/s and can be an alternative to compressed clay barriers, as they offer numerous technical advantages (Rowe, 2010). Among the advantages can be highlights the quick and easy installation; very low hydraulic conductivity if installed properly; small thickness, which increases storage space; in addition to the excellent healing capacity. However, the GCLs use also presents some disadvantages: the potential increases of hydraulic conductivity are highlighted due to incompatibility with contaminant; possibility of dryness; besides that a very thin layer of GCL can facilitate the drilling during or after installation, and the loss of bentonite during installation may cause the reduction of GCL performance, since the key for the hydraulic performance of GCL depends on the quantity of bentonite per unit area, and its uniformity (Bouazza, 2002; Li *et al*., 2008; Guyonnet *et al*., 2009).

Bentonite is responsible for GCL retention property .This is due to the fact that this is composed mainly of montmorillonite, mineral clay with large expansive capacity when being hydrated (Kolstad *et al*, 2004; Shackelford *et al*, 2010). The bentonite voids index largely governs the hydraulic conductivity of the GCL, and there is an inverse relationship between the GCL hydraulic conductivity and the bentonite expansion volume (Petro *et al*., 1997; Di Emilio *et al*., 2008).

When the water molecules are adsorbed by the clay-mineral, the hydrated ions of bentonite expand and restrict the permeate flow. It’s important to emphasize that ions concentration and valence are inversely related to thickness of the adsorbed layer. Therefore, the bentonite is sensitive to changes in the composition of permeate liquid. The hydraulic conductivity of the material increases to fluids with high concentration and valence of ions (Di Emilio *et al*., 2011).

A large number of laboratory studies evaluated the compatibility of GCL with varying types of permeate in order to verify changes in hydraulic conductivity caused by the sample fluid. Continuous studies address various types of contaminants such as ethanol (Petrov *et al*., 1997; Sari & Chai, 2013), hydrocarbons (Toshifumi *et al*., 2005; Mcwatters *et al*., 2016) and organic solvents (Daniel *et al*., 1993; Stark, 2017), among others. From the conclusions obtained by the different studies, the GCL material is appropriate to act as a waterproofing barrier when fully hydrated, but still has increases of hydraulic conductivity when it is fluid with permeate different from water.

Case studies contemplate an analysis on a real scale, with conditions of behavior faithful to the reality, so they are of important research and can be compared to laboratory conditions (Meer & Benson, 2007; Barral *et al*., 2012; Scalia *et al*., 2017). Hydraulic conductivity in the range of $10^{-7}$ to $10^{-6}$ m/s were reported for GCLs dug up with up to 11 years of service in landfill barrier. The high hydraulic conductivity reported in this study was attributed to the loss of expansion capacity of GCL, in addition to formation of cracks, and other macroscopic deformations that occurred during the drying (Meer & Benson, 2007).

There are in the market bentonites modified with different quantities and types of polymers. The additive bentonites are able to maintain their original hydraulic conductivity even with contaminant solutions. Thus, they may be useful for leachate containment, fuel leaks or other contaminated waste. However, they are generally more expensive than natural bentonites (Scalia *et al*., 2014)

On the basis of the foregoing, this article sought to analyses recent advances in GCL application in landfills, checking the types of landfills, as well as their main characteristics, in order to assess, through case studies, the application of GCLs in this context.

## LANDFILLS

Concern for environmental pollution resulting from human activities is a recurring theme in numerous conferences, publications, and government agencies. One of the main activities responsible for soil and groundwater contamination is the inadequate waste disposition, whether it is done in irregular places, or in places that do not receive due environmental protection (Huang *et al*., 2013).

Landfills are waste disposal systems that confer adequate environmental protection, and comprise the set of installations, processes, and procedures aimed at the environmentally appropriate provision of waste in line with the requirements of competent environmental bodies in order to avoid harm or risk to public health and safety, minimizing environmental impacts (Dajic *et al*., 2016). The landfill construction is based on specific engineering criteria and operational norms.

Landfills differ in accordance with the type of waste, with sanitary deposits being for solid urban waste, and hazardous landfills for industrial waste.

Waste from hazardous landfills originates from the activities of the various branches of industry, being represented by sludge's from wastewater treatment plant, ash, oils, paper, wood, alkaline or acid residues, ceramics, fibers, rubber, metal, seepage, glass, pesticides, and also toxic waste (Yilmaz *et al*., 2017). These wastes have characteristics such as flammability, corrosivity, reactivity, toxicity or pathogenicity, and thus deserve greater control and environmental protection in their destination (Şimşek *et al*., 2008).

Sanitary landfills are those intended for domestic, commercial, and public waste. Public waste is those originating from urban public cleaning services, including all wastes of public roads, cleaning of beaches, galleries, streams and land, trimmings of trees etc., and cleaning of fair areas free, consisting of miscellaneous plant debris, packaging etc. (Pinel-Raffaitin *et al*., 2006). The composition of these residues varies according to the site, being basically by organic material, paper, plastic, glass, metal, among others.

### Leachate Features

The leachate resulting from different types of landfills have varied compositions, and these can be derived from the waste composition, and the processes of degradation (Johnson *et al*., 1999; Kulikowska & Klimiuk, 2008). The main pollutants present in the leachate can be: dissolved organic material, methane, volatile fatty acids, recalcitrant materials, toxic metals, bacteria, coliforms, macro inorganic components (calcium, magnesium, ammonia, sulfides, among others), in addition to organic compounds such as aromatic polycyclic hydrocarbons, phenols and nitrogen compounds (Gu *et al*., 2017; Bayard *et al*., 2017).

The leachate from hazardous wastes landfills, such as industrial, have higher concentrations of contaminants than domestic waste landfills (Touze-Foltz *et al*., 2006; Şimşek *et al*.; 2008). The concentration of cations and anions of hazardous waste landfills exceeds that of landfills of domestic waste due to their composition.

The concentrations of the leachate of hazardous landfills are present in the range of 1545 mg/l for calcium, 472 mg/l for magnesium, 3042 mg/l for potassium and 2258 mg/l for sodium (Touze-Foltz *et al*., 2006). In the landfills of domestic waste, the concentrations range from 0.2 – 20 mg/l for cadmium, Cr of 5 – 600 mg/l, Mn of 0.01 – 70 mg/l, and Fe of 0.3 – 220 mg/l (Pinel-Raffaitin *et al*., 2006; Touze-Foltz, 2012).

The composition of landfills leachate, regarding the presence of cations and anions, consists of an important parameter regarding the evaluation of influence of these in the hydraulic conductivity of the GCL and also of its cationic exchange capacity. The GCLs do not have the natural capacity of diffusion and adsorption in the same way as compressed clay, in addition, cations present in the leachate such as calcium and magnesium, can replace the sodium ions of bentonite, thus reducing its capacity of swelling and increasing hydraulic conductivity (Benson *et al*., 2007; GRI, 2013). In order to evaluate the behavior in a more appropriate manner, the following components must be taken into account: composition of the GCL, characteristics of the residues regarding the presence of cations and anions, and also, the composition of the localized clay layer, in many landfill settings, below the GCL layer (Touze-Foltz *et al*., 2006).

### Background cover and waterproofing coating systems settings

Due to the characteristics of residues and leachate, hazardous waste landfills require a more stringent system of background proofing and covering. The system of waterproofing or barriers consists of the use of a draining layer, followed by the protective geotextile, Geomembrane, GCL, draining geocomposite, and another layer of geomembrane and GCL, finishing with compressed soil (Herrten, 2002). In landfills of non-hazardous waste, the system is similar to the detailed for hazardous landfills, however, the configuration comprises only one layer of geomembrane followed by GCL (**Fig. 1**) (Herrten, 2002).

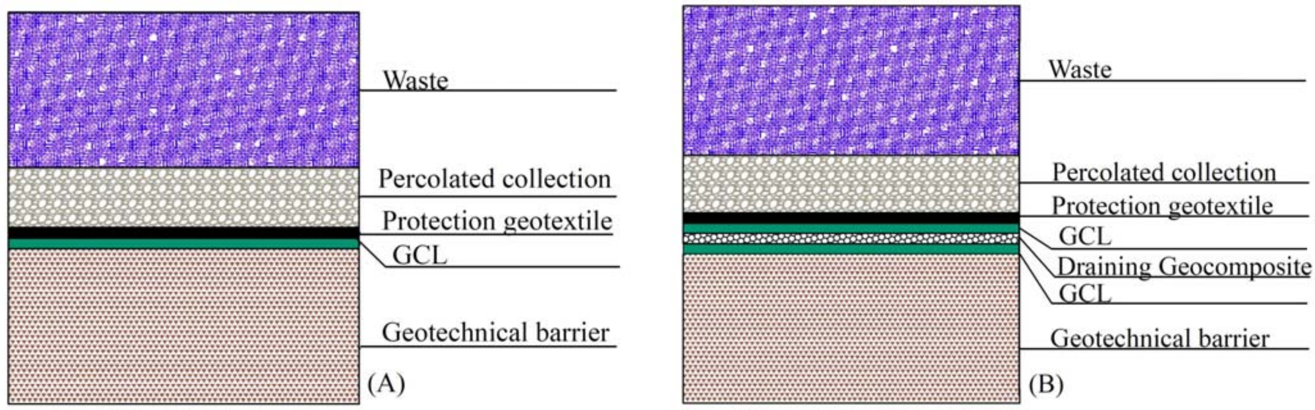


**Fig.1.** Landfill barrier system configurations.
Source: Herrten, 2002 (prepared by the authors). Legend: (A) landfill of non-hazardous waste and (B) hazardous waste landfill.

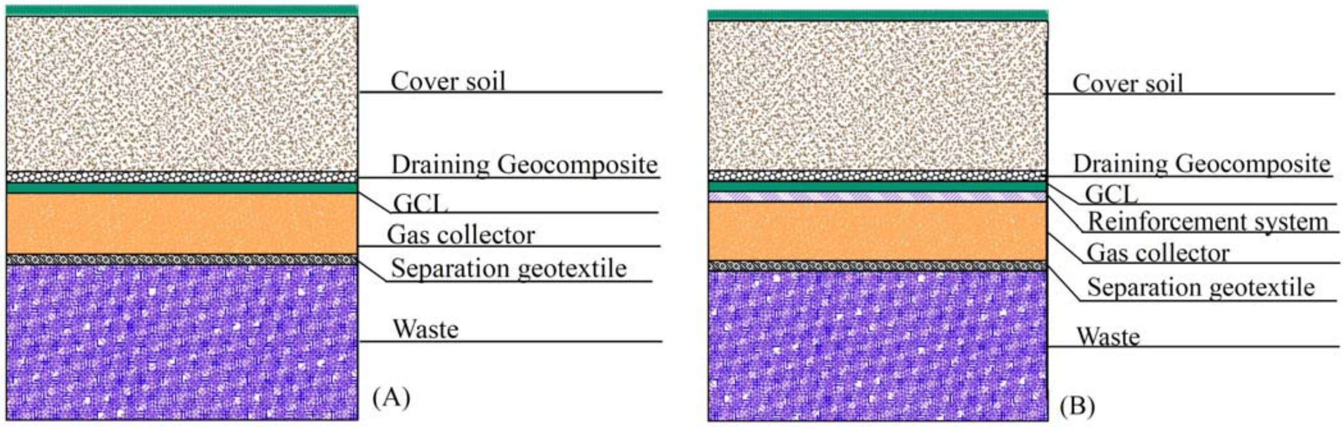


**Fig. 2.** Landfill-coverage system configurations.
Source: Herrten, 2002 (prepared by the authors). Legend: (A) landfill of non-hazardous waste and (B) hazardous waste landfill.

The system of landfills coverage is to prevent the entry of water, especially that of the rain, and to prevent the output of gases generated in landfills. In the same way as the waterproofing system, the coverage of hazardous and non-hazardous waste landfills differs from each other in relation to the use of more components in hazardous landfills due to the characteristics of the gases generated (**Fig. 2**).

In this way, the cover system of hazardous landfills contains, according to Heerten (2002): cover soil, geocomposite draining, geomembrane, GCL, reinforcement system (in some cases), gas collector and separation geotextile. Landfills of domestic or non-hazardous waste comprise the following configuration: cover soil, draining geocomposite, GCL, gas collector and Separation Geotextile (Herrten, 2002).

In both the settings shown in **Figs 1** and **2**, i.e. in both the waterproofing or coverage system, the GCL is employed in conjunction with the geomembrane, consisting of a simple composite barriers system (in the case of non-hazardous landfills) or doubles (hazardous landfills) (Heerten, 2002).

## APPLICATION OF GCL IN LANDFILLS

As shown earlier, for environmental protection, several mechanisms can be employed. Among them are the geosynthetics materials, which are widely used in sanitary landfills, due to their properties and above all the environmental benefit (Liu *et al*., 2015; Bouazza & Touze-Foltz, 2016). According to several research carried out, the geosynthetics act on the removal and drainage of leachate (Junqueira *et al*., 2006; Fourmont & Koerner, 2017), soil proofing (Barroso *et al*., 2006; Dickinson & Brachman, 2008), reinforcement of the walls and slopes of landfills (Giroud *et al*., 1995; Pathak & Alfaro, 2010; Bhowmik *et al*., 2016; Marx & Jacobsz, 2018), in addition to being an important mechanism in detecting any leaks that may occur (Bareither *et al*., 2010; Bouazza *et al*., 2017).

The application of geosynthetics in landfills began in the 80's in the United States, in the containment of solid waste, in a double coating system of GCL in conjunction with a geomembrane (Koerner, 1986; Carroll & Robert, 1986). Over the years the application of the geosynthetics materials, in particular of the GCL, gained popularity in the world scenario as a substitute for the clay coatings compacted in roofing systems and compound backgrounds in landfills (Sunil, 2016). From the 90's the use of geosynthetics in landfills increased significantly, this material being considered a fundamental tool for the construction and environmental protection of landfills (Bouazza & Touze-Foltz, 2016).

Compared to the use of compressed clay layers as a waterproofing barrier, the GCL has more material availability, since it can be shipped anywhere in the world, while for clay it requires the availability of local (GRI, 2013; Sobti & Singh, 2017). Moreover, in landfills that opt for waterproofing systems using compressed clay require a greater layer of clay than the landfills that use geosynthetics materials, such as geomembrane and GCL, for example. In the first case, the clay layer has an average thickness of 1.5 m, while in the second case this is 0.6 m, thus increasing the capacity of the landfill (Anjana & Arnepalli, 2015; Bouazza & Touze-Foltz, 2016).

Another factor that deserves prominence in GCL use compared to clay is the fact that GCL has uniform properties throughout its extension, unlike what can occur in compressed clay use, in which its properties are associated directly with the barrier construction (GRI, 2013). Also, the GCL has lower costs than clay, mainly compared to cases where it should be transported to the landfill site (Sobti & Singh, 2017; GRI, 2013).

## EVALUATION CRITERIA FOR THE APPLICATION OF GCL IN LANDFILLS

The GCL may have numerous applications, both in the waterproofing system and in the coverage of landfills, and, by virtue of these configurations, some parameters of the GCL have a greater or lesser importance to evaluate their performance. In **Table 1**, some of these characteristics of the GCL should be evaluated as to their application in coverage and waterproofing systems of landfills, and these criteria are classified according to the Geosynthetic Research Institute-GRI (2013).

The hydraulic conductivity consists of one of the most important parameters to be evaluated in GCL application, both in coverage and waterproofing systems, since, the presence of cations and anions in the landfills influences directly in the cationic exchange capacity of GCL, and in its conductivity. For the coverage systems, the permeability of the GCL should also be seen in contact with the gases, since, when dry, the bentonite has low permeability to gases (GRI, 2013; Parastar *et al*., 2017).

**Table 1**.GCL evaluation criteria in landfills.

| Criteria | Coverage system | Waterproofing systems |
|---|---|---|
| Hydraulic conductivity | A | A |
| Long-term stability | A | A |
| Contact | C | A |
| Flow of contaminants | C | A |
| Broadcast | C | A |
| Shear | | |
| -Internal | A | A |
| -Interfaces | A | A |
| Puncture resistance | | Usually covered with Geomembrane |
| -Thin Cover | C | |
| -Gravel | B | |
| -Coarse coverage | A | |
| Root penetration | A | D |

Source: Adapted from GRI (2013).
Caption: A – Important, B-project-dependent requirement, C-rarely required, D-not relevant.

The contact and flow of contaminants with the GCL has greater importance in waterproofing system than in the coverage system, due to direct contact with the leachate in this system, which can affect the hydraulic conductivity of the GCL (Benson *et al*., 2007; BENSON *et al*., 2010). Shear resistance is another criteria of paramount importance in the two landfill configurations, since the bentonite when hydrated has low shear strength (GRI, 2013; Fox & Stark, 2015). Moreover, because the geosynthetics are normally installed directly in contact with each other, it can occur to the formation of interfaces, which may possibly represent potential rupture surfaces, if they present low resistance to the shear (Müller *et al*., 2008; Saito & Chai, 2016). In this case, the assessment of resistance by means of shear testing is essential to promote the quality of landfills.

The puncture resistance has greater importance in the coverage systems, because in this setting the GCL layer is usually below the draining layer. Whereas, in the waterproofing systems the GCL layer is together with a layer of geomembrane, in a double-layer system. The penetration of roots should be evaluated in coverage systems, because, in many landfills, after its closure, species of vegetation may arise, both voluntarily and unwittingly, due to lack of conservation and maintenance (Benson *et al*., 2007).

Thus, in addition to the need for a system of coverage and waterproofing that allows the containment of contamination of landfills, tests on geosynthetics materials must also be carried out, in order to ensure the system operation.

Considering the landfill types, as well as the leachate characteristics, and the manner in which they may influence the behavior of geosynthetics materials such as GCL, the following items will be presented in a detailed way three case studies of GCL application in landfills of solid urban waste.

### Case Study 1 (Touze-Foltz *et al.*, 2010)

A study was carried out to investigate the evolution, with time, of Bentonite in the GCL of a landfill operating for six years. Numerous parameters were evaluated by the authors, emphasizing the ability to exchange cationic, hydraulic conductivity.

The GCL extracted for the research was part of the coverage of a landfill in the department "Nord" in France, installed in 2003. The Geocomposite Bentonite installed in this landfill was reinforced by a needle containing bentonite of activated calcium with a minimum mass of 3.5 kg per square meter. The thickness of the soil cover on the geocomposite draining disposed directly over the GLC was approximately 0.5 meters, which would conform to the French standards of geosynthetic use. Between the GCL and the soil cover was applied a draining geocomposite and there was the cultivation of grass over the upper soil.

The study motivation occurred due to the large production of manure in the landfill, which occurred in the year 2006, causing the replacement of the GCL by another of the same characteristics. In the section where the material was exchanged in 2006 the thickness of cover soil was approximately 0.2 meters at the time of sampling. Especially in this space with smaller coverage thickness, grass roots ended up crossing the GCL.

The analyses in the GCL were carried out in six open holes along the landfill cover, these holes comprise places that were in service since 2003, and also those that were in the section replaced in 2006. Some differences in hydraulic conductivity were observed in relation to the holes of the two detailed locations above. In the holes located at the operating sites since 2003 the hydraulic conductivity was $1{,}07\times10^{-6}$, $1{,}71\times10^{-6}$, and in the holes of the section replaced in 2006 were $6{,}91\text{x}10^{-6}$. These differences can be explained by various criteria, such as lower thickness, lower initial water content, reduced soil layer thickness in coverage and the presence of roots more significantly.

The study showed that bentonite had a complete exchange of sodium for calcium, even for samples with two years of service. This was evidenced by the bentonite expansion tests and the quantification of the concentration of various cations in the clay. Another conclusion was that the presence of roots was found especially in the GCL samples located under a shallower cover.

The research also showed the desiccation in the GCL and a low water content in the samples and, despite the realization of hydration for the permeability tests, the samples did not have expansion capacity and the hydraulic conductivity measured was high for a waterproofing barrier.

### Case Study 2 (Bradshaw & Benson, 2013)

In relation to the application of GCL in the landfill proofing system, the tests in these cases are carried out prior to the operation of the embankment, in order to verify the behavior of the GCL in contact with the leachate, simulating situations of landings, using tensions of confinement to assess the behavior due to the waste presence.

The study of Bradshaw & Benson (2013) evaluated the leachate effects of solid urban waste in hydraulic conductivity and in the cationic exchange of GCL applied in a barriers system. The GCL used in the study was composed of a layer of betonite-Na granularity wrapped by two geotextiles (woven fabric in cut film and geotextile woven of non-woven staple fibers) reinforced by containing needle, with a minimum mass of 3.66 kg/m².

The test consisted in the configuration of a composite barrier system for hydration. This type of configuration look for to evaluate real conditions of GCL application in landfills, evaluating the hydration in the different subgrids in which the GCLs hydrate. The authors selected four subgrids (Sand Torpedo, Red Wing Clay, Boardman's silt and Cedar clay Rapids) to represent different types of soil (sand, slime and clay) and porosity. This hydration occurred for 30 and 90 days, in order to simulate the start and end period of disposal of the waste.

In relation to hydration, the highest indices were observed in the GCL that was hydrated used the subgrid with Torpedo sand, and the smallest in the Cedar clay Rapids. After hydration the GCL was permeated with synthetic and real leachate of municipal solid waste landfills, being these "typical" and "strong". The "typical" leach has medium characteristics of the leachate, while the "strong" leachate comprises a more critical configuration in the landfills, in this leachate, there is a greater ion force and a greater preponderance of divalent cations. Finally, the hydraulic conductivity of the GCL was evaluated using voltages of confinement voltages of 70, 270 and 520 kPa. The permeation of the GCL was conducted for 342 and 1281 days, with most tests with minimum duration 950 days.

In relation to the cationic exchange, bentonite sodium cations replaced by more than 80% mainly by magnesium and calcium, and in lower concentrations of potassium (K). The leachate composition influenced the cationic exchange, since these had greater concentrations of Mg and Ca.

The comparison of hydraulic conductivity of GCL permeated with typical synthetic leaching with the real showed no significant differences. However, in the strong leachate, differences were observed between the synthetic and the real, being the first superior more than 2.0 times. This fact was justified by the authors due to high concentration of particulates in suspension and generation of gases during the rehearsals. Another factor compared was the hydraulic conductivity of the typical and strong leaches, and this was superior in the strong leachate in relation to the hydraulic conductivity under the effect of the stress of confinement, this decreases with the increase of the stress, regardless of the leachate used for testing or the condition of hydration. However, the stress of confinement did not affect the cationic exchange in the GCLs, and this occurred throughout all the confined voltages evaluated.

In landfill-proofing systems using GCL many parameters must be evaluated in order to ensure the operation of barriers and environmental protection. The evaluation of the behavior of the GCL in these systems is the subject of numerous studies, ranging from the use to landfills of municipal waste and also the hazardous ones, with different configurations of systems, leachate and tensions.

## ADVANCES IN APPLICATION OF GCL IN LANDFILLS: GCL PERFORMANCE IN CONTACT WITH RECIRCULATION LEACHATE

Numerous studies have been carried out over the last decade in order to evaluate the GCLs performance used in landfills, mainly in relation to its hydraulic conductivity, chemical compatibility, swelling of the water, capacity of autocurement, characteristics of diffusion, gas migration, mechanical behavior, among others (Kong *et al*., 2017). However, these studies are based only on analyses considering the contact of the GCL with the conventional leachate of landfills. However, landfills may have different configurations in relation to leachate management. Conventional landfills, the leach generated due to the waste decomposition is only collected and intended for proper treatment, while in other configurations the recirculation of this leachate occurs.

The leachate recirculation process is employed in order to speed up the process of degradation of solid waste in landfill (Pinto, 2000; Andrade, 2014). According to Pohland & Kim (1999) recirculation promotes better contact between insoluble substrates, nutrients and microorganisms, and at the same time treats the leachate by accelerating the waste anaerobic degradation, that is, the recirculation of leachate creates ideal conditions of humidity and temperature for digestion of the organic fraction of the solid urban waste in landfills (Shrike, 2004). Furthermore, recirculation also acts in the stabilization of waste, optimizing biogas production and expanding commercial opportunities for the same (Andrade, 2014).

The use of GCL in landfills with leachate recirculation is vetoed by some regulatory agencies, due to the few studies related to the recirculate leachate characteristics. The impediment of alternative coatings, such as GCL, in landfills with leachate recirculation is usually based on the perception that recirculated leaches are more concentrated or aggressive compared to conventional leaches and therefore they may adversely affect the hydraulic conductivity of a clay component of an alternative coating, resulting in higher leakage rates (Bradshaw *et al*., 2016). US EPA, for example, indicates the realization of more studies in this area, in order to guide decision makers, on the behavior of the GCL in contact with the leachate of recirculation.

In this sense the study developed by Bradshaw *et al*. (2016) sought to provide an analysis of the GCL's performance of the waterproofed landfill system in contact with the leachate of recirculation, verifying how this leachate affects the hydraulic conductivity and cationic exchange of GCL clay coatings.

### Case Study 3 (Bradshaw *et al.*, 2016).

The GCL used in the study in question contained bentonite-Na conventional granulation encapsulated between a mesh fabric of crevice and a non-woven geotextile of discontinuous fibers, united by needle perforation. Its composition consists of 80% of Montmorillonite, 7% of plagioclase, 6% of cristobalite and trace levels ($\leq$ 2%) of calcite, illita, mica, Heulandita, gypsum and quartz, with a cationic exchange capacity of 69.1 ± 11.1 cmol +/kg.

Laboratory tests were conducted in such a way as to assess how the hydraulic conductivity of the geosynthetics clay coatings was affected by the recirculated and conventional leachate of urban solid waste. The hydraulic conductivity tests were conducted with the GCL using seven leachate of landfills with leaching recirculation and a leachate from a landfill with conventional leaching management. The concentration of cations and anions of leachate is described in detail in the study. The main characteristic that can be illustrated in relation to the leachate characteristics of landfills with recirculation and the conventional, the concentrations of cations and anions of the first, are smaller in relation to the second, respectively.

Based on the tests carried out, the authors verified that the long-term hydraulic conductivity of GCLs permeated with recirculated leaching of solid urban waste (1.0-$2.0\times10^{-11}$ m/s) is comparable to the hydraulic conductivity to the conventional leachate ($2.0\times10^{-11}$ m/s) and less than hydraulic conductivity to long-term water (2.1–$9.8\times10^{-11}$m/s), demonstrating that recirculated leaches have no greater adverse impact on hydraulic conductivity than conventional leaches. However, long-term hydraulic conductivity for all leachate is greater (1.4 to 2.9 times) than hydraulic conductivity to water reported by tests using conventional test methods, such as ASTM D5084 (ASTM 2003), for rated confinement (70 kPa).

In relation to the cationic exchange, the concentrations of sodium, magnesium and potassium (respectively, $Na^+$, $Mg^{+2}$ and $K^+$) were much smaller in the recirculated leach than in the conventional leach, resulting in a gradual exchange of cations and a gradual increase of hydraulic conductivity. However, the final hydraulic conductivity, after more than four years of permeation was almost identical to the GCLs with recirculated and conventional leachate (respectively, $1.6\times10^{-11}$ m/s e $2.0\times10^{-11}$ m/s). The hydraulic conductivity of the GCL permeated with the two leachate was stabilized, since, the concentrations of the leachate for $Na^+$, $Mg^{+2}$ and $K^+$ were no longer variables temporarily.

The hydraulic conductivities for the landfill leachate with recirculation and conventional remained low after the exchange of cations. This fact is explained by virtue that ammonium ($NH_4$) is a primary and monovalent cation, which replaces the cations in the exchange complex, causing the relative proportion of monovalent and divalent cations in the exchange complex to remain essentially the same as the that present in the bentonite of a new GCL. Another fact resulting from this analysis is that hydraulic conductivity remains low due to the modification of the ionic strength of the conventional and recirculated leaches (typically < 300 mm).

The study also evaluated, by means of a revision of the state-of-practice of the performance of landfills with recirculation of leaching, the rates of leakage of composite coating with GCLs in two landfills of solid urban waste with leachate recirculation (Bareither *et al*., 2010). The study landfills contained a double coating system, consisting of a leakage detection system between the coatings, consisting of a geocomposite drainage layer (Bradshaw *et al*., 2016). In relation to the top coating, it was a layer of geomembrane, GCL and granular layer. Through the monitoring of the leak control system, it can be verified whether the recirculation of the leachate influenced the increase of the leaks. The rates of leakage were very low, with a maximum of 0.35 L/(m²-year), being that the rates of leakage before and after the recirculation were similar.

## CONCLUSIONS

The hydraulic conductivity of geosynthetics materials, such as GCL, consists of the most important parameter to be evaluated in relation to its use in landfills. The composition of landfills leachate as to the presence of cations and anions, should also be considered, since these compounds can influence the characteristics of the GCL, such as hydraulic conductivity and also their ability to exchange cationic.

It is understood the importance of evaluation and continuous monitoring of the quality of the GCL, be this evaluation made before the landfill, in cases of the barrier system, as after the closure of the landfill in the cover systems. There are GCL parameters that must be evaluated according to the system in question, waterproofing or covering. These evaluations promote greater security in the landfill construction, and also in the environmental protection.

Another important factor of considering in the application of GCL in landfills is the recirculating configuration of leachate, fact this little widespread in the landfills of the world, however with many benefits. The evaluation of GCL's behavior in these types of landfills was detailed, showing that the use of geosynthetics materials, in particular the GCL, in landfills with leachate recirculation does not result in significant modifications in hydraulic conductivity of the same, as well as in the cationic exchange between the GCL and the cations and anions present in the leachate. In addition, in relation to the concern for higher leakage rates in the GCL due to the lechate recirculation, through the analysis of field-scale study data with GCL composite coating, it was observed that this type of configuration of landfills can be effective in maintaining low leakage rates, even with leachate recirculation.

Therefore, it can be concluded that the use of geosynthetics materials in landfills provides countless benefits, besides the ease of installation, and the cost benefit, these materials act with an important ally in environmental preservation. In this way, it is important to evaluate the behavior of these materials in order to guarantee these benefits and also the behavior of these in contact with the leachate of landfills.

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